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LINEAR PROGRAMMING MODEL FOR THE OPTIMIZATION OF THE BIODIESEL SUPPLY CHAIN IN THE MINDANAO ISLAND OF THE PHILIPPINES

Yra Mae C. Camacho, Kristin Joy E. Davila, Ysabela Angela V. Flores, Julie Anne D. del Rosario*

Department of Chemical Engineering, College of Engineering, University of the Philippines Diliman, Quezon City, Philippines 1101

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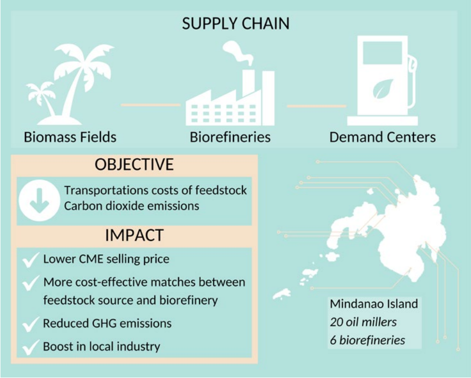
*Corresponding author
jddelrosario2@up.edu.ph

Graphical abstract



Abstract

Biofuels are known to have several advantages over fossil fuels including, but not limited to, high abundance of resources, negligible SO_x emissions, lower NO_x emissions, and more environment-friendly processes. In the Philippines, the biofuels industry is anchored onto the Biofuels Act of 2006 which mandates the use of biofuels made from indigenous sources such as coconut. Despite this, biodiesel is still less preferred by consumers over conventional fuel due to its high cost. This can be attributed to high production costs of biodiesel, wherein 18-28% is credited to transportation of products. This work proposes a linear programming model to reduce the overall cost of biodiesel by minimizing the transportation cost in the Philippine biodiesel supply chain, using the Mindanao cluster as case study. Multiple scenarios were done to gauge the impact of varying the supply allocation and biodiesel blend on the supply chain. The optimal supply allocation, transportation cost, and carbon footprint of each scenario were determined. A new facility locator feature was also added as an extension of the program. Results also showed high reproducibility using easily accessible programming tools such as Microsoft Excel and Python.

Keywords: Biofuels, Supply allocation, Transportation cost, Linear Programming, Philippines

1.0 INTRODUCTION

Biofuels, such as bioethanol and biodiesel, are known to have several advantages over fossil fuels including, but not limited to, high abundance of resources, negligible SOx emissions, lower NOx emissions, and more environment-friendly processes [1]. Biodiesel produces 93% more energy than that invested in its production (25% for bioethanol), reduces greenhouse gas emissions by 41% (12% for bioethanol), and generally has a more efficient conversion of raw materials to fuel making it more cost-efficient than bioethanol [2].

In the Philippines, biodiesel is commercially derived from coconut alone. The abundance of coconut plantations in the country has been reported to be up to 3.5 million hectares as of 2018 [3]. The industry in the Philippines is anchored onto the Biofuels Act of 2006 (RA 9367), which requires the use of biofuels made from indigenous sources to reduce dependence on imported fuels [4]. The Act introduced incentives to further encourage local production and distribution of biofuels by mandating a minimum 1% biodiesel blend (B1) in all diesel fuels by February 2007, to be increased to a 2% blend (B2) by 2009. The Department of Energy (DOE) followed it through with a progressive target layout until 2030, culminating at 30% (B30). However, as of 2020, DOE reported that biodiesel blending remains near 2.5% (B2.5). Despite raw materials being sourced locally, production costs for biodiesel are still higher compared to petroleum diesel resulting to higher market price, thus consumers still prefer the latter. Moreover, current biorefineries in the country are underutilized, with only 38% of the combined capacity of 575 million liters as of 2017 being used [5]. In addition, biodiesel also competes with other profitable coconut-based products such as nutraceutical creations in terms of coconut oil (CNO) share, adding to the difficulties faced by the biofuel industry in the country.

The biodiesel supply chain is both an enabling and impeding mechanism for the growth of the biofuel industry. Generally, the biodiesel scene is plagued by the lack of infrastructure and supporting policies needed for an efficient and cost-effective delivery of dense feedstock all year round. The 20-35% of the total production cost is associated with the biomass supply cost, and 90% of which is attributed to logistics. Researchers then have developed an interest in designing an optimized supply chain, not only for biodiesel, but for the entire biofuel landscape [6].

This work aims to build a linear programming model set in the Philippine biodiesel supply chain, using the Mindanao cluster (see Figure 1), where the facilities are more spread out across the island and thus attracts optimization efforts, as a case study. Of the 607.9 MLPY production nationwide (as of 2020), Mindanao accounts for around 21.81% of production. The computations shall be geared toward a secured market for the CNO products of the coconut millers through matching with the biorefineries. Biodiesel production cost is seen to be cut down with the lower transportation costs implied by the resulting optimal network, entailing a lower market price for the end-product and encouraging the implementation of higher biodiesel blends. This study may also serve as a supplement and decision aid for government protocols and initiatives which could lead to a boost in the local biodiesel industry.

2.0 METHODOLOGY

Given a set of CNO millers (sources), coconut oil products must be allocated to a set of biorefineries (sinks) in a network determined by minimizing the cost associated with transportation and thereby optimizing transportation routing. This is done by formulating a linear programming (LP) model that utilizes available information such as miller and biorefinery capacities, distances between millers and biorefineries, fuel price, and fuel efficiency. The objective function of the model is subjected to mathematical constraints and assumptions based on set scenarios.

LP Model Formulation

For CNO allocation between the source *m* and the sink *b*, the optimization objective in Equation (1) is expected to minimize the transportation cost (TC) incurred in bringing over the CNO product from millers to biorefineries. It is a function of fuel efficiency (FE), fuel price (FP), and the distance between the oil millers and biorefineries. The source is considered as the origin of the material to be allocated (CNO), while the sink is at the receiving end.

The objective function was based on the model of Foo et al. [8] which minimizes carbon footprint from transportation vehicles. Transportation cost was then calculated using the following equation:

$$TC = (FE)(FP)\sum_{b=1}^{B}\sum_{m=1}^{M} x_{m,b}d_{m,b} \quad (1)$$

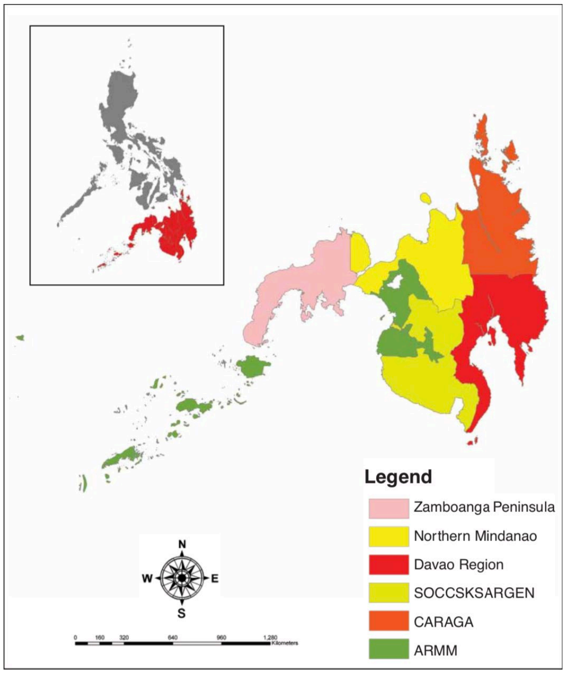


Figure 1 A map of the Mindanao island (Philippine map in inset) [7]

The model serves two scenarios: (1) biorefinery capacity meeting or exceeding biodiesel market demand, and (2) biorefinery capacity failing to meet market demand for biodiesel, as to be expected when a regulatory body decides to mandate a higher blend percentage. The objective function is subjected to a unique set of constraints for two scenarios with different target outputs.

In the first scenario, the locations of all facilities of interest, both biorefineries and millers, are already set. The allocation (i.e. the amount of CNO each miller provides to each biorefinery) matrix is then produced through optimization of Equation (1) with the following constraints:

1. The total volume of CNO from millers to one biorefinery must be equal to the CNO demand of the biorefinery.
2. The total volume of CNO from one miller to the biorefineries must be less than or equal to the available supply of the miller.
3. The amount of allocated CNO from a miller to a biorefinery must be less than or equal to the demand of the biorefinery.
4. Allocated CNO must be greater than or equal to zero.
5. There are no provisions for building a new or for shutting down an existing biorefinery.

$$\sum_{m=1}^{M} x_{m,b} = S_b \quad \text{for b} = 1, 2, \dots, \text{B} \quad (2)$$

$$\sum_{b=1}^{B} x_{m,b} \le R_m \quad \text{for m} = 1, 2, \dots, \text{M} \quad (3)$$

$$x_{m,b} \leq S_b \tag{4}$$

$$x_{m,b} \geq 0 \tag{5}$$

On the other hand, the second scenario calls for the determination of the location of the new biorefineries to be built. The approach resembles that of a facility location problem which aims to find the best location for new facilities based on a set criterion such as minimizing the conveying cost[9].

A decision variable is then introduced, identifying the optimal choice among a matrix of potential locations. It must only have a binary value – 1 if a biorefinery would be constructed in the prospect location and 0 otherwise. This value would be multiplied to the demand of the biorefinery. If a biorefinery would be constructed in a prospect location, the CNO allocation to the same biorefinery must follow the constraint. If no biorefinery would be constructed in the prospect location, the demand would be equal to zero.

The new objective function for the second scenario is shown to be:

$$TC = (FE)\,(FP)\left(\sum_{b=1}^{B} y_b f_b + \sum_{b=1}^{B}\sum_{m=1}^{M} x_{m,b} d_{m,b}\right) \tag{6}$$

The value for the linearity variable, f_b, was set to a very small number (1 x 10^{-6}) for it to have negligible effects on the transportation cost [10].

Constraints for this model are shown below. The first, third, and fourth constraints are similar to that of the first scenario, with the inclusion of the decision variable. The second constraint states that the entire CNO capacity of each miller must be used up in the allocation.

$$\sum_{m=1}^{M} x_{m,b} = S_b y_b \quad \text{for b } = 1, 2, \ldots, \text{B} \tag{7}$$

$$\sum_{b=1}^{B} x_{m,b} = R_m \quad \text{for m } = 1, 2, \ldots, \text{M} \tag{8}$$

$$x_{m,b} \leq S_b y_b \tag{9}$$

$$x_{m,b} \leq 0 \tag{10}$$

$$y_b \in \{0,1\} \tag{11}$$

Summarized in the flowchart diagram in Figure 2 is the logic followed in building the model. It can be concluded that two models have been developed, one concerned with the optimal network between source and sink and the other dealing with the establishment of new biorefineries. The model is limited to the supply chain from the millers to the biorefineries duly recognized by the Department of Energy and Philippine Coconut Authority in Mindanao. In the second scenario, potential biorefinery sites are set to one for each province in the Mindanao Island.

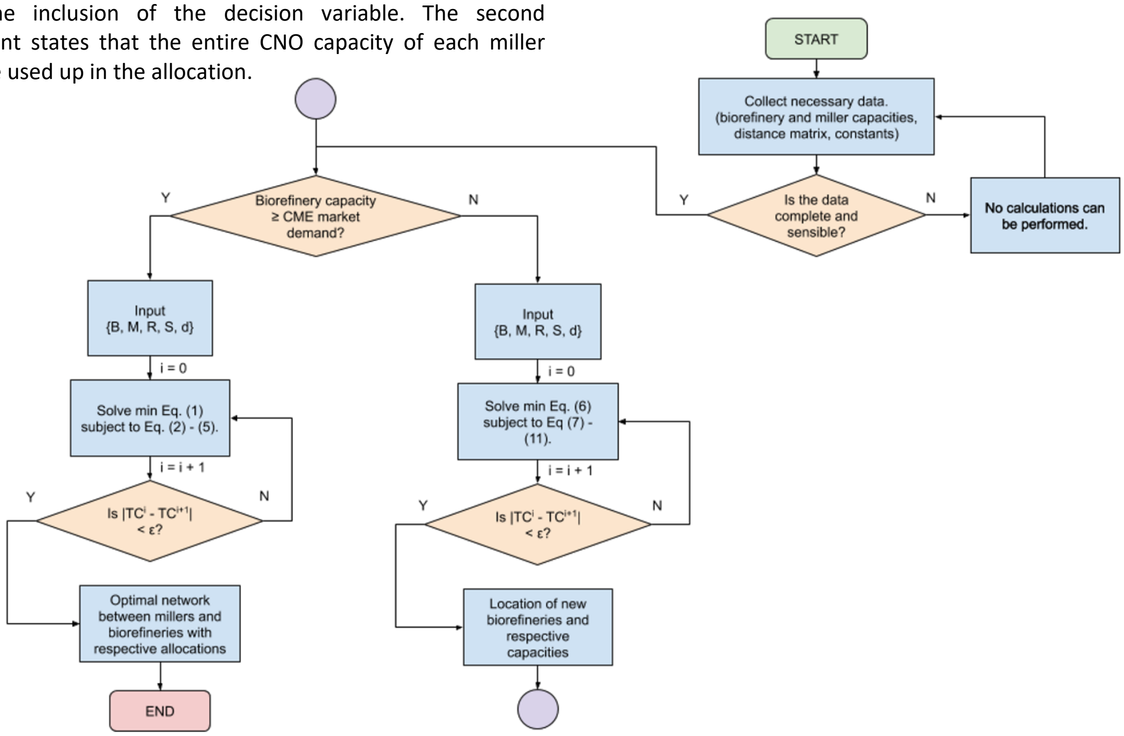


Figure 2 Flowchart diagram of model building for a biodiesel supply chain network

Data Collection

The list of recognized oil millers with their rated capacities located in Mindanao was obtained from the Philippine Coconut Authority [11]. A total of twenty (20) oil millers were enumerated. Ten (10) of which are considered suppliers of CNO for CME production based on the available information, while ten (10) do not supply CNO for CME production (refer to Supplementary Material). On the other hand, the list of biorefineries in Mindanao was obtained from the Department of Energy [12]. A total of six biorefineries were found; five of which are operational, while one is still under construction (refer to Supplementary Material). Distances from the millers to the biorefineries were obtained through the Driving feature of Google Maps in order to consider only routes with accessible roads for trucks.

In determining the optimal location for building new biorefineries, geospatial data is needed to effectively recommend a site for construction. Geographic information system (GIS) 2011 data were taken from the Philippine GIS Data Clearinghouse for each of the twenty-one (21) inland provinces of Mindanao [13]. Each province is represented by a single point by generating the mean coordinates for each province using QGIS. Additionally, the transportation emission factor used for the calculations was 0.207 kg-CO_2 per ton-mile, as derived from the US Environmental Protection Agency. Fuel efficiency data were also determined for 2020 and 2030 scenarios through interpolation and extrapolation of data from the Environmental and Energy Study Institute [14]. The local diesel price in 2020 was approximated by taking the average of the retail pumping prices in Mindanao from January 21, 2020 to September 15, 2020 using the data provided by the Department of Energy [15].

LP Models

Two cases were considered for this study: (1) CNO allocation under a specified percentage of supply from oil millers; and (2) CNO allocation under an increased biodiesel blend in a future scenario. The B5 blend was used for the first case since the current biorefineries are already capable of producing the required CME for B5 [17]. Meanwhile, B10 blend was used for the second case considering a gradual increase in the implemented biodiesel blend in the country.

The following assumptions were held true for both cases:

1. All oil millers and biorefineries can meet their annual rated capacities.
2. All the listed oil millers remain operational and there are no additional oil millers in Mindanao during the covered timeframe.
3. Driving routes are the same for both cases and no additional roads are constructed during the covered timeframe.
4. Transportation via the shortest driving distances were used.
5. All of the oil millers designate the same percentage of their products for CNO production.
6. All CNO products of Miller 1 are supplied to only Biorefinery 1 and is, therefore, immediately subtracted from the demand of Biorefinery 1. This is done since Miller 1 and Biorefinery 1 are listed as the same facility and an input of zero in the distance matrix would automatically result to zero allocation.
7. Biodiesel demand values follow those in the Biodiesel Demand Outlook of the Philippines, 2018-2040 from the Department of Energy [16]. Relevant values are those from 2020 and 2030 as shown in Table 1.
8. CME to CNO ratio to produce CME is 1 L CME:1 kg CNO [5].
9. Mindanao continues to supply 21.81% of the total CME demand in the country [12].
10. Urban heavy-duty diesel trucks are used for transporting CNO. Fuel efficiency values are taken from the Environmental and Energy Study Institute [17]. Local diesel price in 2020 fluctuates around Php 38.03/L [15], which is used in this study.

Calculations were performed on Microsoft Excel and PyCharm, an open-source integrated development environment (IDE) for the Python programming language. For the calculations done in PyCharm, the optimal solutions were obtained with the use of a Solving Constraint Integer Programs (SCIP) solver, a non-commercial tool for solving mixed integer (linear and nonlinear) and constraint integer programs [18]. An interface from Python to the SCIP Optimization Suite, PySCIPOpt, was also installed to run the solver. Meanwhile, the Solver add-in was used for the solutions done in Microsoft Excel.

Table 1 Biodiesel Demand and CME & CNO Requirement Values Used in the Study [9]

Year	Biodiesel Demand (MLPY)	Blend	CME Requirement (MLPY)	Mindanao CME Requirement (MLPY)	Mindanao CNO Requirement (MTPY)
2020	11149.34	5%	557.47	121.60	121600
2030	16575.44	10%	1657.54	361.56	361560

Case 1

This scenario assumes that all the CNO products of the oil millers are used for CME production. Ten (10) out of the twenty (20) millers were considered to supply CNO for CME production to meet the B5 demand. Also, the sinks for the model only comprise of the five (5) currently operational biorefineries.

Case 2

This case explored the implementation of the B10 blend in a future scenario. Millers are then expected to have ramped up production to cater to CNO market demand and biorefinery capacity that current operating facilities cannot meet. This is in contrast with the B5 mandate explored in Case 1. According to the Renewable Energy Management Bureau, a 16,575 million liters per year (MLPY) biodiesel demand is forecasted for the year 2030 [16]. If Mindanao's 21.81% share holds true until 2030, Mindanao is expected to produce 361.56 MLPY of biodiesel. However, as of October 2019, the combined capacities of both operational and under-construction biorefineries are not enough to satisfy the increased demand with a 78.96 MLPY deficit. Therefore, new plants should be constructed for the implementation of B10. Meanwhile, in terms of supply, the combined supplies of the ten (10) millers considered in Case 1 will not be enough to meet the increased demand. Thus, in Case 2, the CNO producers that previously do not supply for CME production are now also included as sinks. Additional assumptions for Case 2 states that the biorefinery to be constructed are assumed to have a capacity of 40 MLPY as previously recommended by DOE [19]. Moreover, the biorefinery under construction is assumed to be operational by 2030.

For the first part of the calculations, the breakeven allocation of CNO millers to the biodiesel industry was calculated. Breakeven refers to the required percentage of total CNO production to be dedicated to biodiesel production, under the assumption that all millers will designate the same portion. Using the breakeven percentage of 30.61%, the available CNO from the millers were first distributed among the six (6) operational biorefineries to determine which oil millers will still have excess supply.

Equations (2) - (5) from Case 1 are also used as constraints for Case 2. Although the breakeven amount was calculated, all the CNO were not yet allocated since the new biorefineries were not yet specified. From these calculations, four underutilized oil millers were identified: Millers 10, 11, 15, and 17. This denotes that the four millers still retained unused CNO supply even after the maximum capacities of the biorefineries were already satisfied. These underutilized supplies will then be re-allocated to the new biorefineries. Aside from volume allocation, Case 2 also recommends the optimal locations for plant construction.

The resulting locations from this model were then added to a new distance matrix for the third part of this case. This was done in order to account for any changes in the CNO allocation after these new biorefineries have been constructed.

3.0 RESULTS AND DISCUSSION

Case 1

Given that the currently registered biorefineries are already capable of producing the B5 blend and are awaiting its implementation within the year, Case 1 assumes that 100% of the CNO supply of each miller is allotted for CME production.

Solving the objective function in Equation (1) subject to the constraints in Equations (2) – (5), the optimal allocation of CNO and the optimal results for Case 1 are shown in Tables 2 and 3, respectively.

Table 2 Allocation of CNO for Case 1 at 100% (MTPY)

	B_1	B_2	B_3	B_4	B_5	Under-utilized
M_1	0	0	0	0	0	0
M_2	0	0	0	12000	0	0
M_3	0	0	0	0	11700	48300
M_4	0	0	12000	0	0	0
M_5	0	0	8700	0	21300	0
M_6	0	0	0	0	0	45000
M_7	0	17400	0	3600	0	0
M_8	0	0	0	14400	0	0
M_9	9600	6600	6300	0	0	0
M_{10}	0	0	3000	0	0	0

Table 3 Optimal Results for Case 1

Transportation Cost (PHP/y)	22,752,957.71
Fuel Consumption (L/y)	598,289.71
CFP (kt CO_2/y)	1.60

It can be noted that this case resulted to an underutilized CNO supply from Millers 3 and 6. The underutilized supply may be redirected to another market or new biorefineries may be built for the surplus.

Case 2

As reported in the Biodiesel Demand Outlook of the Philippines for the years 2018 to 2040, the implementation of the B10 blend is expected by 2030 [17]. Case 2 then simulates the scenario at which the blend increase takes effect.

With the expected increase in blend, both the available CNO supply (1-10) and the biorefinery capacities (1-5) in Case 1 will not be able to meet the projected market situation. Therefore, the oil millers currently not contributing to the biodiesel industry were also included as sinks to address the increase in demand. New plants were also opened to accommodate the demand increase.

In building the model, the production deficit for the year 2030 was found to be at 78.96 MLPY. By assuming that the biorefineries to be constructed can produce 40 MLPY of CME at maximum, two new facilities were estimated to be added to the network.

For the first part of Case 2, the breakeven allocation was calculated to be 30.61%. The values for the breakeven calculations were derived from all registered oil millers (1-20) and from both the operational (1-6) and the two new biorefineries. Solving the objective function in Equation (1) subject to the constraints in Equations (2) – (5), the optimal allocation of CNO for Case 2 at breakeven is shown in Table 4.

Table 4 Allocation of CNO for Case 2 at Breakeven (MTPY) Using the Existing Network

	B_1	B_2	B_2	B_4	B_5	B_6	Under-utilized
M_1	0	0	0	0	0	0	0
M_2	0	0	0	3673	0	0	0
M_3	0	0	0	0	0	18367	0
M_4	0	0	0	0	0	3673	0
M_5	0	0	0	0	0	9183	0
M_6	0	0	0	0	0	13775	0
M_7	0	6428	0	0	0	0	0
M_8	0	0	0	4407	0	0	0
M_9	0	6887	0	0	0	0	0
M_{10}	0	0	0	0	0	0	918
M_{11}	0	0	0	14731	0	0	23756
M_{12}	0	0	0	0	0	1224	0
M_{13}	0	0	0	0	33000	49650	0
M_{14}	0	0	0	0	0	29570	0
M_{15}	0	0	0	0	0	14885	19553
M_{16}	0	107	0	0	0	0	0
M_{17}	0	0	0	0	0	0	35773
M_{18}	0	1996	0	7187	0	0	0
M_{19}	13763	8581	30000	0	0	0	0
M_{20}	0	0	0	0	0	9673	0

From Table 4, the allocation model returned non-zero values for the underutilized capacities despite being evaluated at breakeven. This is due to the inclusion of the capacities of the new facilities in determining the breakeven percentage. Since only the operational biorefineries were reflected in the allocation model, the underutilized capacity returned by the model pertains to the amount of CNO allocated to the new biorefineries.

Table 5 Facility Location Model for the New Biorefineries

	M_{10}	M_{11}	M_{15}	M_{17}	Status
P_1	0	0	0	0	Closed
P_2	0	0	0	0	Closed
P_3	0	0	0	0	Closed
P_4	0	0	0	0	Closed
P_5	0	0	0	0	Closed
P_6	0	0	0	0	Closed
P_7	918	23756	0	15326	Open
P_8	0	0	0	0	Closed
P_9	0	0	0	0	Closed
P_{10}	0	0	0	0	Closed
P_{11}	0	0	19553	20447	Open
P_{12}	0	0	0	0	Closed
P_{13}	0	0	0	0	Closed
P_{14}	0	0	0	0	Closed
P_{15}	0	0	0	0	Closed
P_{16}	0	0	0	0	Closed
P_{17}	0	0	0	0	Closed
P_{18}	0	0	0	0	Closed
P_{19}	0	0	0	0	Closed
P_{20}	0	0	0	0	Closed
P_{21}	0	0	0	0	Closed

To provide the necessary data for the potential facility locations, the landmass of Mindanao was discretized into its respective provinces. This was done to objectively recommend a candidate location from any of the provinces in Mindanao. Only inland provinces were included in the model since the scope of the study is limited to land transportation.

To obtain the optimal location and allocation for Case 2, the surplus capacity from Millers 10, 11, 15 and 17 were redistributed to the 21 candidate sites for construction by solving the new objective function in Equation (6) subject to the constraints in Equations (7) – (11).

Table 6 Allocation of CNO for Case 2 at Breakeven (MTPY) Using the New Network

	B_1	B_2	B_2	B_4	B_5	B_6	B_7	B_8
M_1	0	0	0	0	0	0	0	0
M_2	0	0	0	2160	0	0	1513	0
M_3	0	0	0	0	0	18367	0	0
M_4	0	0	0	0	0	3673	0	0
M_5	0	0	0	0	0	9183	0	0
M_6	0	0	0	0	0	13775	0	0
M_7	0	0	0	6428	0	0	0	0
M_8	0	0	0	4408	0	0	0	0
M_9	0	6887	0	0	0	0	0	0
M_{10}	0	918	0	0	0	0	0	0
M_{11}	0	0	0	0	0	0	38487	0
M_{12}	0	0	0	0	0	1224	0	0
M_{13}	0	0	0	0	0	49650	0	0
M_{14}	0	0	0	0	0	29570	0	0
M_{15}	0	0	0	0	0	0	0	34437
M_{16}	0	0	0	107	0	0	0	0
M_{17}	0	0	0	1550	0	28660	0	0
M_{18}	0	0	0	9183	0	0	0	0
M_{19}	13763	2419	30000	6162	0	0	0	0
M_{20}	0	0	0	0	0	9673	0	0

The optimal locations recommended by the facility location model are Province 7 (Davao Oriental) and Province 11 (Misamis Occidental) as seen in Table 5. Each biorefinery is set to open with a rated B10 capacity of 40 MLPY. Ultimately, the distance matrices of P_7 and P_{11} were integrated into the existing network to determine the final allocation of CNO shown in Table 6.

Table 7 Optimal Results for Case 2

Transportation Cost (PHP/y)	14,245,505.10
Fuel Consumption (L/y)	374,585.99
CFP (kt CO_2/y)	1.25

The optimal value generated for Transportation Cost, Fuel Consumption and Carbon Footprint for Case 2 are presented in Table 7.

Validation and Error Analysis

Scenario-specific solutions are subject to the availability and preciseness of the data needed to run the model. Sensitivity analyses are therefore not applied in this study. The accuracy of the objective function in this application becomes prone to errors in the assumptions made, such as the actual amount of CNO allocated by the millers for biorefinery use or the fraction thereof. Nevertheless, the model is expected to yield the optimized values using a different set of values. Robust programming may be integrated into the model to ensure smooth execution of the optimization model in the future.

4.0 CONCLUSION

A mathematical model has been developed for the optimization of a biodiesel supply chain with respect to transportation cost, creating an optimal network between CNO millers and biorefineries. Framed as a linear programming problem, the solution also provided the optimized allocation of CNO between sources and sinks. The model was used in two (2) scenarios for the Mindanao Island cluster as case studies. In the latter application presented, the LP model was reformulated to yield the locations of new biorefineries to be built for the expected B10 implementation in 2030. The approach is expected to serve as a decision aid for the planning and implementation of biodiesel systems, while also being highly reproducible as the calculation tools are easily accessible (Python and Microsoft Excel) and leaving room for modification to accommodate improvements in accuracies in the scenarios.

It is recommended to cross-check the findings from proposed model to the real scenario, iteratively enhancing the quality of the model. The distance matrix can also be refined through finer discretization of land area, specifying a pool of meticulously selected candidate sites rather than merely choosing a province. Other researchers interested in logistics planning, particularly facility matching and location optimization, and in renewable energy landscaping and mobilization may use the models and assumptions developed in this study. In future applications of this work, other feedstock may be considered such as those already appearing in the local research scene (used cooking oil and microalgae, among others). The scope of the biodiesel supply chain network may also be extended to include plantations, the main feedstock source, and oil depots, which are considered the endpoint of the chain in most of the literature available. The calculations may be expanded to include other clusters (Quezon and Manila) since it is likely that these networks are interconnected to a great extent.

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Nomenclature			
B	Set of biorefineries	**CFP**	Carbon footprint
M	Set of oil millers	**TFP**	Transportation emission factor
b	Element of *B*	**CNO**	Coconut oil
m	Element of *M*	**CME**	Coco methyl ester
$x_{m,b}$	CNO allocation from miller *m* to biorefinery *b*	**MLPY**	Million liters per year
y_b	Decision variable for the construction of new biorefineries	**MTPY**	Metric tons per year
f_b	Linearity variable	**FP**	Fuel price
S_b	CNO demand of biorefinery *b*	**TC**	Transportation cost
R_m	Available CNO supply of miller *m*	**FE**	Fuel efficiency
$d_{m,b}$	Distance from miller *m* to biorefinery *b*		

References

[1] R. Ruan, Y. Zhang, P. Chen, S. Liu, L. Fan, N. Zhou, K. Ding, P. Peng, M. Addy, Y. Cheng, E. Anderson, Y. Wang, Y. Liu, H. Lei, and B. Li, 2019."Biofuels: Introduction," In *Biofuels: alternative feedstocks and conversion processes for the production of liquid and gaseous biofuels*: Elsevier, 3-43, https://doi.org/10.1016/B978-0-12-816856-1.00001-4

[2] J. Hill, E. Nelson, D. Tilman, S. Polasky, and D. Tiffany, 2006"Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels," Proceedings of the National Academy of Sciences of the United States of America, Vol. 103, No. 30: 11206-11210,.https://doi.org/10.1073/pnas.0604600103

[3] P. Pamplona, "Hybrid coconut: its potential to help overcome poverty," Agriculture Monthly, December 2018 [Online].Available: https://www.agriculture.com.ph/2018/12/09/hybrid-coconut-its-potential-to-help-overcome-poverty/ [Accessed May 2020]

[4] Department of Trade and Industry, "Biodiesel - securing the future of Philippine industries,"(n.d.) [Online]. Available: http://industry.gov.ph/industry/biodiesel/ [Accessed May 2020]

[5] P. Corpuz, 2017. *Philippine Biofuels Situation and Outlook*, RP 1713, United States Department of Agriculture Foreign Agricultural Service, Manila, Philippines

[6] S.D. Ekşioğlu, A. Acharya, L.E. Leightley, and S. Arora, 2019. "Analyzing the design and management of biomass-to-biorefinery supply chain," *Computers & Industrial Engineering*, 57(4): 1342–1352 doi: 10.1016/j.cie.2009.07.003

[7] Regional Development Office, 2010. National Economic and Development Authority, *Mindanao Strategic Development Framework 2010-2020*, Philippines,

[8] D. Foo, R. Tan, H. Lam, M. Aziz, and J. Klemeš. 2013,"Robust models for the synthesis of flexible palm oil-based regional bioenergy supply chain," *Energy*, 55: 68-73. doi: 10.1016/j.energy.2013.01.045

[9] B. Liu, 2009 "Facility Location Problem" In *Theory and Practice of Uncertain Programming. Studies in Fuzziness and Soft Computing*, Springer, Berlin, Heidelberg, 157-165. https://doi.org/10.1007/978-3-540-89484-1_11

[10] J. Pedroso, A. Rais, M. Kubo, and M. Muramatsu, 2012 "Capacitated facility location problem", In *Mathematical Optimization: Solving Problems using SCIP and Python*, [e-book], [Online]. Available: https://scipbook.readthedocs.io/en/latest/flp.html

[11] Philippine Coconut Authority 2018. Data from: *Summary of coconut oil millers* [dataset], Philippine Coconut Authority Trade Directory.

[12] Department of Energy, 2017. Data from: *List of Accredited Biodiesel Producers* [dataset], Department of Energy List of Biodiesel.

[13] PhilGIS, 2011. Data from: *Datasets by Region*, PhilGIS: Free Philippine GIS data for educational and nonprofit use [Online]. Available: http://philgis.org/datasets-by-region [Accessed: May 2020]

[14] United States Environmental Protection Agency, 2020, Data from: *Emission factors for greenhouse gas inventories* [dataset], Greenhouse Gas (GHG) Emissions [Online]. Available: https://www.epa.gov/sites/production/files/2020-04/documents/ghg-emission-factors-hub.pdf [Accessed: May 2020]

[15] Department of Energy, 2020. Data from: *Mindanao Prevailing Retail Prices* [dataset]. Department of Energy

[16] Economic Research Institute for ASEAN and East Asia, *Study of Renewable Energy and Its Effective Usage in East Asia Summit Countries,* ERIA Research Project Report No. 9, ERIA, 2018

[17] Environmental and Energy Study Institute 2015. Data from: *Fact sheet - vehicle efficiency and emissions standards* [dataset]. Available: https://www.eesi.org/papers/view/fact-sheet-vehicle-efficiency-and-emissions-s [Accessed: May 2020]

[18] Zuse Institute Berlin, 2020 *"SCIP Optimization Suite: SCIP,"* [Online]. Available: scipopt.org/index.php [Accessed: June 2020]

[19] R. Lotilla, 2007 "Biofuels Initiatives in the Philippines", *California Biomass Collaborative 4th Annual Forum*, Symposium conducted at Sacramento, California, March